SOFTWARE FOR SEISMIC STABILITY AND DISPLACEMENT OF SLOPE

LOGICIEL POUR STABILITE SEISMIQUE ET DEPLACEMENT DE PENTE

A. Ghosh

Scientist, Central Building Research Institute
Roorkee, India

SYNOPSIS : Newmark's concept of computing the permanent displacement under seismic loads has been combined with the conventional limit equilibrium analysis to compute the displacement of slopes. A computer program has been developed to compute the displacement from the digitised input data of the acceleration time history. The program can take into account the water pressure on the intersecting planes and on the planes of the tension crack. The effect of stabilising anchors if present is also taken care of in addition to static surcharge loads. The programme calculates the conventional static factor of safety, resistance against sliding, the critical acceleration, exciting force, relative velocity with time and the cumulative displacement. The critical acceleration computed through the software, presented in this paper, serves as a very handy tool for a site engineer to get the first hand information about the stability of the slope for a given acceleration time history. The software described in this paper finds a general application in geotechnical engineering where ever the slope undergoes a translatory motion for its failure i.e the force equlibrium is established to compute the factor of safety for the conventional limit equilibrium analysis.

INTRODUCTION

Newmark (1965) while delivering the Fifth Rankine lecture, first proposed to compute the permanent displacement of earth and rock fill dams when subjected to strong seismic forces instead of computing the conventional factor of safety. This concept of Newmark is well established to day. Credit goes to Sarma (1975), Makdisi and Seed (1977) to bring the concept to the level of common application. Subsequently work has been done to compute the displacement of blocks and slopes subjected to strong motions by Chang et al. (1984) and Lin et al.(1986). Vonthun and Harris (1981) computed the displacement of a rockfill dam when subjected to an earthquake load utilising this concept. Ghosh and Haupt (1989) computed the seismic stability of rock wedge combining the concept of Newmark and the limit equilibrium method.

In the present paper, the software developed for computer aided stability analysis of slopes under seismicity and the computation of permanent displacement is described.

MECHANISMS OF SLIDING

During an earthquake , two possible reasons may cause the loss of stability of a slope. Firstly the time dependent earthquake forces together with the static forces may bring down the factor of safety below one for a short while. In other words, earthquake forces may decrease the resisting force and increase the driving force in such a way that ultimately the factor of safety drops below unity and sliding starts. But the stable condition will be regained immidiately after the earthquake if the engineering properties of the rock slope on the failure plane are not altered due to sliding.

Secondly, if by the earthquake, pore pressure in the sliding plane increases strength characteristics of the sliding plane will get reduced possibly inducing the slope to slide even under static condition. In such a situation till the excess pore pressure generated is not dissipated, the factor of safety even after the earthquake will not rise to its pre-earthquake value.

It is assumed that,

1)Sliding plane exists or develop during the earthquake.

2)The slope slides as a rigid body.

3)Strength characteristics of the sliding plane do not change along with the displacement or velocity.

4)The slope under goes a tranalatory motion for its failure.

MATHEMATICAL FORMULATIONS

The limit equlibrium analysis of a rock slope has been delt with previously in great details. Hence in this paper, the conventional way of determining the factor of safety is not further outlined. The resistance against sliding (RS) is obtained as the difference between the total resisting force and the driving force

$$RS = RF - DF \qquad (1)$$

Sliding of the slope starts if RS becomes negative i.e DF is higher in magnitude than RF. Ghosh and Haupt (1989) showed that the condition of sliding due to seismicity reduces to -

if $RS > TIF_{dyn}(T)$ --Sliding does not start

$RS = TIF_{dyn}(T)$ --Condition of Dynamic equilibrium

$RS < TIF_{dyn}(T)$ --Sliding starts

Where TIF_{dyn} is the total induced dynamic force at any point of time T. The details of the mathematical formulations are deliberately not given here and can be found in the reference mentioned in the text.

COMPUTATION OF DISPLACEMENT

For the computation of displacement the acceleration time history must be available in the digitised form. Since the time history is considered to be linear within one time step, the discritisation must be dense enough to describe the true accelration variation with sufficient accuracy for the highest relevant frequency.

At every time step the $TIF_{dyn}(T)$ is calculated and compared with RS and the conditions of sliding are checked. The precise time of initiation of sliding T_0 - if not fallimg at the end of a time step - is computed by linear interpolation. The relative acceleration of the wedge or the block of the slope at the end of any time step is computed by dividing the total resisting force with the mass m = W/g of the wedge or the block.

The relative velocity increases as long as the relative acceleration remains positive and decreases as soon as the relative acceleration becomes negative and comes to zero at that moment when the integral of the relative acceleration becomes zero. The relative displacement increases during the total duration of sliding and obtains a finite magnitude when the relative velocity becomes zero. The cumulative displacement is computed at the end of every time step by integrating twice the relative acceleration.

DESCRIPTION OF THE SOFTWARE

A PC based computer program has been developed to carry out the seismic stability analysis of a slope under going failure as described above. The program takes into account the water pressure on the intersecting planes and on the plane of the tension crack. The effect of stabilising anchors if present is also taken care of in addition to the static surcharge loads. The program calculates the conventional static factor of safety, optimised anchor force and also its orientation to raise the existing factor of safety to the desired value, resistance against sliding, the critical acceleration, exciting force, relative velocity with time and the cumulative displacement. The program also computes the induced stress in the stabilising anchors due to displacement and checks against thier failure due to over stressing. In the eventuality of anchor failure, the progaram recomputes the static factor of safety and resistance against sliding without the anchor force. The digitized acceleration time history serves as one the input parameters along with the geological data of the slope and the engineering parameters of the slope materials. The input time steps are discritised to 0.01 sec and for every discritised time step the exciting force due to seismicity is calculated and compared with the resistance against sliding. The point of initiation of sliding is interpolated linearly between two successive discritised time step. The acceleration is integrated twice to compute the displacement. The program has the flexibility to produce the graphical output optionaly through the multicolour pen plotter. For a wedge type of failure, from the input geological data the program checks the possibility of the formation of wedge and also for the tension crack before proceeding for the detailed calculation. The built in check incorporated for the program checks for the illogical input data and terminates with diagnostic error messages identifying the illogical input parameters.

The program has a pre processor which is essentially the input parameters stored in a file. The main module of the program does all the computations as mentioned above. In the post processor module the output files are opened and all the results are stored. For the graphical output the user is given an option through the interactive quarries before the graphic output is created and stored in a seperate file. The block diagram of the program is shown in Fig 1.

Through the software one can compute the magnitude of acceleration above which the slope starts sliding or conversely below which no permanent displacement takes place. This serves as a very handy tool for a site engineer to get the first hand information about the stability of the slope for a given acceleration time history.

A sample output of the program is shown in the Fig 2.

CONCLUDING REMARKS

The software described in the paper being PC based can be installed in any DOS platform and serves as an effective tool for a slope design engineer.

A wide ranging parametric study can be done thro' the program very quickly and the efficacies of the stabilisation measures adopted to reduce the permanent displacement by increasing the resitance against sliding can be quickly evaluated through the program described in this paper.

Allowing the factor of safety to go below one for a finite duration of time and taking decision on the basis of displacement is a well calculated risk which a design engineer may like to take depending on the situations.

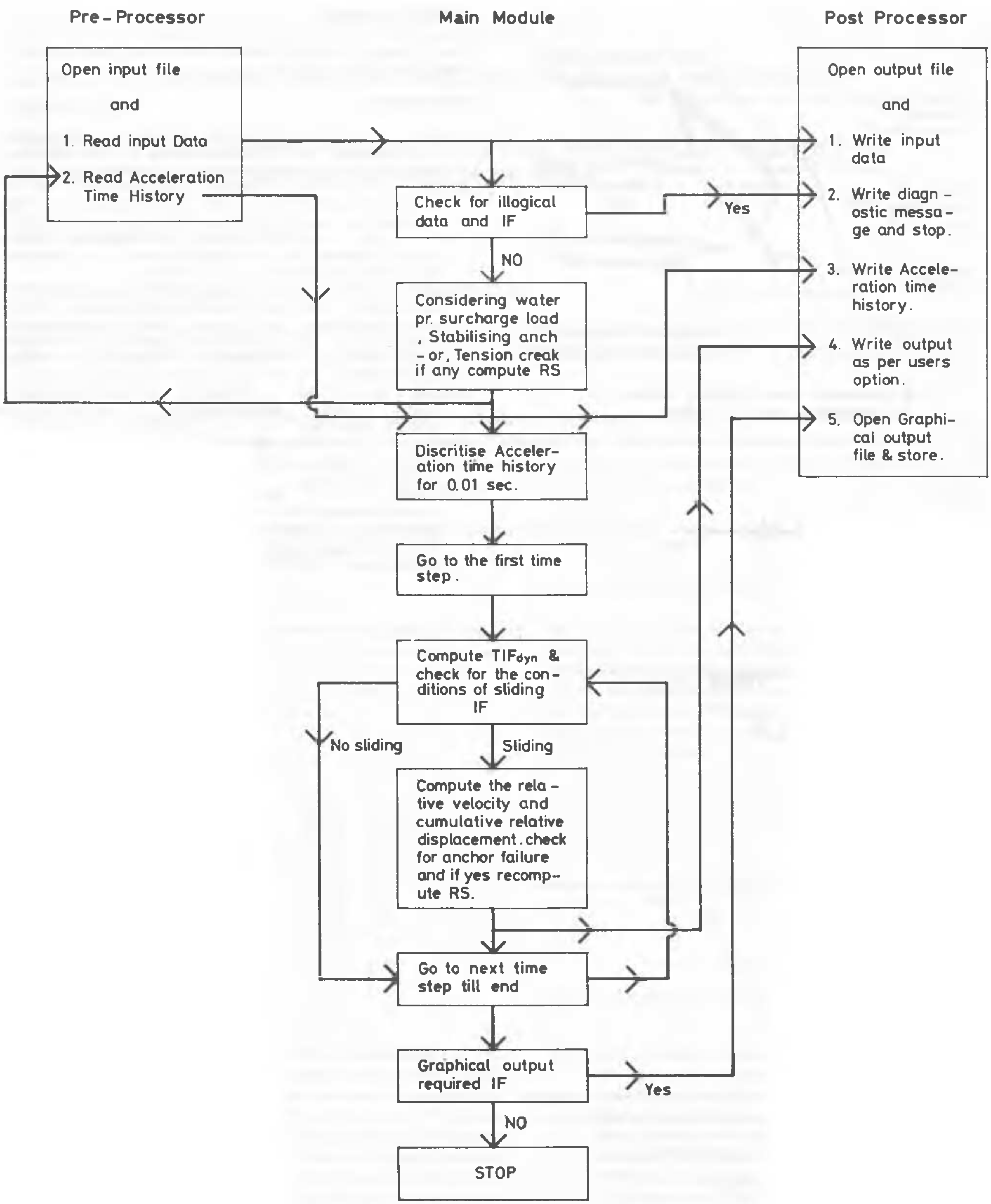

Fig. 1 Block diagram

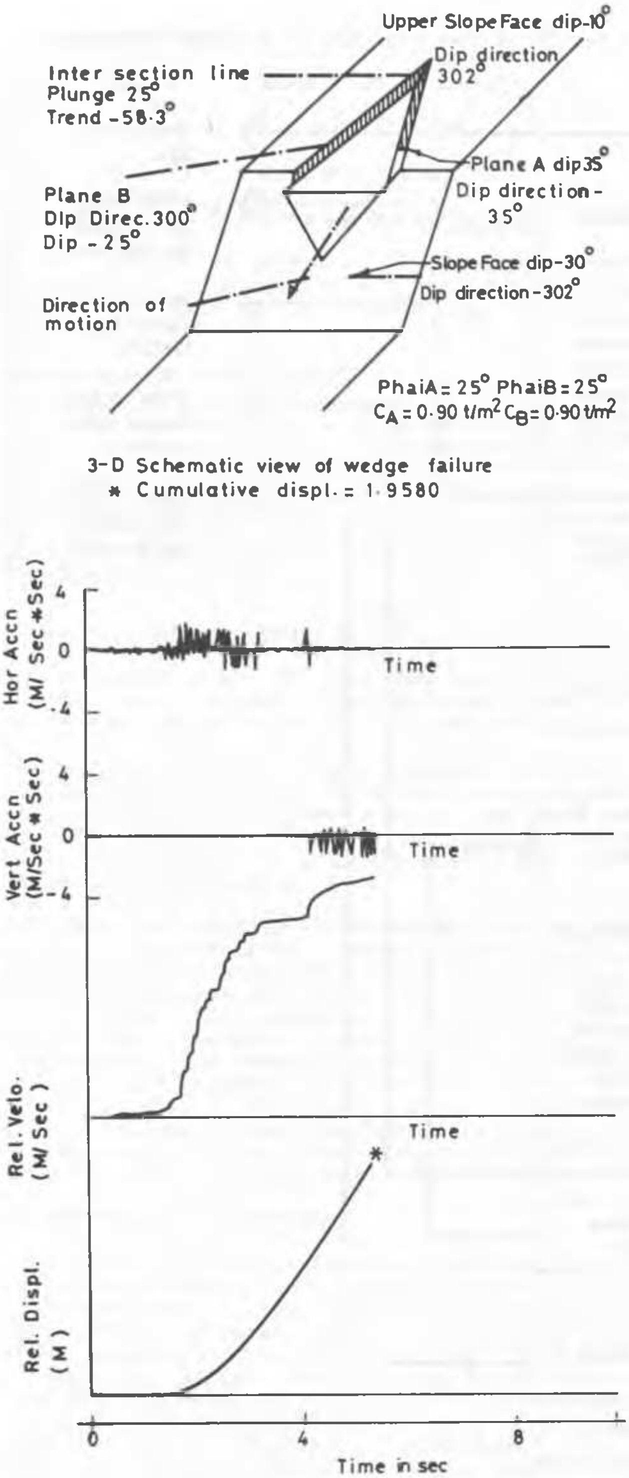

Fig.2. SAMPLE OUTPUT

ACKNOWLEDGEMENT

The paper is published with the permission of the Director. C.B.R.I.

REFERENCES

Chang, C.J., et al.(1984).Seismic displacement in slopes by limit analysis. Jl. Geotech. Engineering. ASCE.110(7):800-814.

Ghosh,A., et al. (1989).Computation of the seismic stability of rock wedge. Jl. Rock Mechanics and Rock Engineering.22:109-125.

Lin, J.S. et al.(1986).Earthquake induced displacement of sliding blocks. Jl. Geotech. Engineering.ASCE.112(1):44-59.

Makdisi, F.I. et at.(1977).A simplified procedure for estimating earthquake induced deformations in dams and embankments. University of Califonia, Barkley,Earthquake Engineering Research Centre, Report No.77/79.

Newmark,N.M.(1965). Effects of earthquakes on dams and embankments. Geotechnique. 15(2):139-160.

Sarma, S.K.(1975).Seismic stability of earth dams and embankments. Geotechnique. 25(4):743-761.

Vonthun, J.L. et al(1981).Estimation of displacement of rockfill dams due to seismic shaking. Intl.Conf.Recent advances in Geotechnical Earthquake Engineering and Soil Dynamics. 1:417-423.